EFFECTS OF FLUSHING ON ELECTRO-DISCHARGE
MACNINED SURFACE

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ABSTRACT

Electrode discharge machining is the process for shaping hard metal and forming deep by arc erosion in all kind of electro conductive material. The objective of this research is to study effect of flushing parameter of EDM of tungsten carbide on the machining characteristics. The effectiveness of the EDM process with tungsten carbide is evaluated in term of surface roughness, and microstructure of the workpiece also to optimize the machining parameter of machining tungsten carbide using EDM machine. Experiment on tungsten carbide material was carried out using difference pressure flushing machining parameter with copper tungsten electrode. Base on the flushing pressure gauge at machined EDM AQ55L the range pressure flushing on this machine EDM is 0.025 to 0.125 Mpa. In this experiment, the jet flushing pressure is used for flow the dielectric into the gap spark between electrode and workpiece. Better machine performance is obtained generally with the electrode as the cathode and the workpiece as the anode. The optimal flushing pressure is found to be at 0.1 MPa. This is the best flushing rate that will be chose in the parameters because it has small surface roughness. There is little variation on the surface roughness of the workpiece, although at 0.1 Mpa the surface finish tends to be better. At 0.05 MPa to 0.1 Mpa, the grain solid debris begins to decrease on the surface at this pressure. Effects from the higher spark formed a large void and the grains bunchy exist in that area also sticks together in the void.

ABDTRAK

Electrode discharge machining (EDM) adalah satu proses untuk membentuk logam dan permotongan yang dalam pada bahan kerja yang mempunyai kekerasan yang kuat, ia terjadi daripada hakisan arc dalam beraliran elektrod dengan material. Objektif dalam kajian ini ialah untuk mempelajari kesan-kesan terhadap bilasan parameter pada bahan kerja tungsten carbide dengan ciri-ciri pemesinan. Keefektifan daripada proses (EDM) terbahagi kepada kadar kekasaran permukaan bahan dan permukaan bahan kerja selepas pemesinan di lakukan. Dalam kajian bahan kerja tungsten carbide, perbezaan bilasan tekanan pemboleh ubah mesin dengan electrode copper tungsten. Merujuk kepada mesin EDM model AQ55L, tekanan bilasan akan dibuat secara manual pada mesin ini. Kadar keupayaan tekanan yang dilakukan antara 0.025 hingga 0.125 Mpa. Prestasi mesin lebih baik diperolehi kerana biasanya elektrod sebagai katod dan kerja sebagai anod. Tekanan bilasan yang optimum adalah berada pada tekanan 0.1 MPa. Ini merupakan kadar pancuran yang paling baik kerana ia mempunyai kekasaran permukaan yang kecil. Walaupun perubahan pada kekasaran permukaan kerja adalah kecil namun tekanan pada 0.1 MPa mempunyai kemasan permukaan yang labih baik. Pada 0.05 MPa hingga 0.1 Mpa, didapati biji-bijian bermula berkurangan pada permukaan bila tekanan bilasan ditingkatkan. Kesan-kesan daripada bunga api lebih tinggi menyebabkan lubang dan lembah besar terhasil membolehkan bijian terkumpul didalamnya. Pada tekanan bilasan 0.125Mpa, keadaan pemotongan adalah tidak stabil. Ini kerana cecair leburan yang terhasil daripada percikan bunga api pada kawasan yang sama.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Electro-discharge machining, commonly known as EDM, is a machining device that use electrical energy to shape and forming a metal parts. Electro-discharge machining (EDM) is one of the most accurate manufacturing processes in performs the job on hard metal and other materials that are difficult to be done by conventional machine. The application of EDM is limited on machining electrically conductive workpiece material because EDM has the capability of cutting the material regardless of their hardness or toughness.

Electro-discharge machining (EDM) works by eroding the material that appears in the electrical discharge as a conductive path is established between the electrode and the material being machined. So there is no actual contact between the two components and a workpiece that sometimes dipped in a dielectric to develop a potential difference between the workpiece and electrode. This material is responsible for generating spark from tool and the work piece. A shaped tool, electrode, or wire can be used to generate the sparks between the workpiece and electrode. The electrical discharge machining takes place within a bath of dielectric fluid in order to prevent premature sparking. It also conducts electricity between the electrode and the work piece. [10]

Flushing is one of the important factors in operation Electro-discharge machining (EDM). Flushing pressure is produced from both the top and bottom flushing nozzles. The pressurized of fluid help in spark production and in eroded metal particle removal the debris when it is done and also as a cooling the electrode and workpiece. Wong, Y.S. et. al [6].

Electrical discharge machining has the advantages compare to the other machining techniques due to its ability to create complex and intricate parts with a high degree of accuracy. This process is able to machine the hard materials, where the others machining processes would have a difficulties. Another advantage of EDM is its ability to machine parts on an extremely small scale.

1.2 PROBLEM STATEMENT

EDM is commonly used in tool, die and mould making industrial for machining heat treated ceramic material such as tungsten carbide. Electrode discharge machining is the process of electrically removing material by making continuous spark between the electrode and the workpiece in the dielectric

Flushing is one of the important factors in operation Electro-discharge machining (EDM). Flushing pressure is produced from both the top and bottom flushing nozzles. The pressurized of fluid help in spark production and in eroded metal particle removal the debris when it is done and also as a cooling the electrode and workpiece. Wong, Y.S. et. al [6].

Flushing is a useful procedure for removing debris from the discharge zone, however some debris are not clearly removed from the machined surface. Therefore this debris may effects the machined surface and also reduces the material removal rate during machining.

The physical properties of the fluid influence the breakdown voltage and the ignition delay. However, the debris concentration in the fluid will modifies these parameters, decreasing the dielectric strength by many orders of magnitude. Flushing is a useful procedure for removing debris from the discharge zone, however some debris are not clearly removed from the machined surface. Therefore this debris may effects the machined surface and also reduces the material removal rate during machining. Even if it is difficult to avoid concentration gradients and inaccuracy. Lonardo, P. M. [4].

The characteristics that required by a dielectric used in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. Besides these basic requirements, practical criteria need to be considered in the selection of a dielectric including the health and safety, and maintenance. Tool wear and workpiece removal rates are affected by the type of dielectric fluid flushing. Wong, Y.S. et. al [6].

1.3 OBJECTIVE OF THE STUDY

i. To determine the effect of flushing on the machined surfaces of electro-discharge machining such as surface roughness (Ra), and microstructure.
ii. To optimize the machining parameter of machining tungsten carbide using EDM machine.

1.4 SCOPE OF THE STUDY

i. This research to measure the surface roughness (Ra), and microstructure of machined surface.
ii. This project consider the variable of flushing pressure, while other the parameters machine such as polarity, peak current, pulse duration (on-time) and pulse interval (off-time) are constant.
iii. The die sinking EDM Sodick machine model AQ55L will be used to machine tungsten carbide using copper tungsten tool electrode.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION EDM MACHINE

Electrical discharge machining or EDM is a thermal erosion process in which the work piece material is removed through a series of rapidly reoccurring electrical discharge between electrode (cutting tool) and an electrical conductive work piece in a presence of a dielectric fluid.

There is a voltage gap between the electrode and the work piece that form the spark vaporizes minute particles of the work piece material, which is then washed out from the gap by the continuously flushing dielectric fluid. EDM is a diverse process that produces products ranging from tiny electric connectors, medical parts, and automatic stamping dies and aircraft body panels. EDM has replaced much of the machining, grinding steps needed in die making which represents the largest single use of EDM. Die component cut with EDM can often be made in a single piece no matter how complex the internal form. The single piece die are always stronger than those made of segments.

The EDM process also has its limitations. The metal removal rates are low compared to conventional metal cutting processes. Complex materials require lead-time for fabrication and are consumable while cutting and the work piece materials must be conductive. The basic components of the electrical discharge machinery are relatively simple. The electrode is attached to the RAM, which is connected to one pole of the electric power supply. The work piece is connected to the other power supply. The work piece is then positioned so that there is a small piece between work piece and electrode. This gap is flooded with dielectric fluid which acts as insulator until the power is turned out. Once on, the machine delivers thousands of electric pulses per second to the gap and erosion begins. As erosion continues the machine control advances the electrode through the material and is containing a constant gap distance.

As a pulse of DC Electricity reaches the electrode and part an intense electric field develops in the gap, microscopic contaminates suspended in the dielectric fluid are attracted by the field and concentrated in the field's strongest point. These contaminates builds a high conductivity along the gap as the field's voltage increases. These materials in the conductive bridge heat up. Some pieces ionize to form a spark between the electrode and the work piece. At this point the both the temperature and pressure in the channel increase generating a spark. A small amount of the material melts and vaporizes from the material and the work piece at the point of spark contact. A bubble composed of gaseous by products vaporize rapidly expands rapidly outward from the spark generated. Once the pulse ends the spark and the heating action stop collapsing the spark channel. Dielectric fluid then rushes into the gap forcing melted material out from the surfaces. This EDM residue consists of solidified parts of material and gas bubbles.

The EDM cut can have several observable surface layers. The top surface is created when expelled molten material and small amount of electrode material melt forms spheres on part of the surfaces, this layer is easily removed. The next layer is a recast or white layer as EDM has altered the piece metallurgical structure. All work occurs during the on time so pulse duration and the number of cycles per second. The sum of on time and off time is important. Metal removal is proportion to the amount of energy during on time that energy is controlled by the time variables. The peak Amperage or intensity of the spark and the length of the on time. The larger the on time the more the metal erodes.

Off time also affects speed and stability of the EDM cut. Too shorten off time, the ejected material will not flood easily with the dielectric fluid. The next spark may then be not stable. The duty cycle is the percentage of on time relative to the total cycle time. The higher the duty cycle means increased cutting efficiency. Gap distance between work piece material and the electrode also impact the material removal rate. Generally the smaller the gap the better the accuracy and the surface finish are and the metal removal rate is.

There is a direct relationship between the voltage and the gap. The servo system must sense the voltage between the electrode and the work piece. This signal controls the servo system and maintains a constant gap distance between the electrode and the work piece through out the EDM cycles. Most power supplies provide a cut off or fault protection system to stop power flow to the system if a short circuit between the electrode and the work piece occurs. To successful EDM flushing is very essential, where the EDM dielectric system introduces clean dielectric to the EDM cutting zone flushing away the EDM debris and cools the work piece and electrode. Popular dielectric fluids for EDM systems are hydrocarbon and silicon based oil.

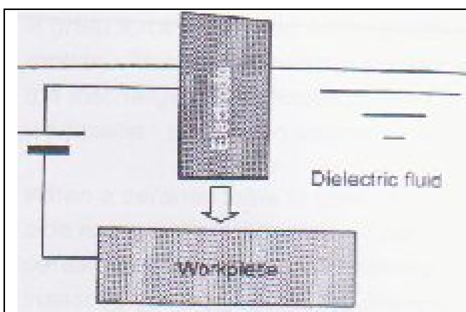
The dielectric fluid is pumped through nozzles through the electrode or through the work piece or some combination of them to continuously flush the work area. Flushing requires careful consideration because of the high forces involved forcing the fluid through small passageways. Many low-pressure holes are preferred to many high-pressure holes. The EDM electrical polarity is usually has a positive charge and the workpiece polarity is negative and depend on the negative and positive workpiece.. Although the metal removal is smaller than if the polarity is reversed. A positive electrode polarity protects the electrode from excessive wear and preserves its dimensional accuracy.

Che Haron et. al [11], Copper and graphite are the most common electrode materials. Whatever the electrode material is used it should combine high strength and high melting point. To help the electrode resist the erosion of the corners where electric field is concentrated. Making the electrode is an important step in ram EDM. The electrodes are shaped on all types of machines. Since the copper material turns to dust, the machine must be equipped with a system of dust control and evacuation.

2.2 APPLICATION ON EDM MACHINE

Electrode discharge machining is the process of electrically removing material by making continuous spark between the electrode and the workpiece in the dielectric. Based on book Nc Power Supply for EDM LN2-LQ Machining Manual, Table 2, show briefly about how the spark produces between workpiece and electrode.

Table 2.1: Show briefly explained about the spark sequence. [14]

<table>
<tr>
<td>
</td>
<td>The electrode approaches the workpiece through the medium of dielectric fluid while applying no-load voltage direct current.
• The voltage direct current level is determined by machining condition and parameter.</td>
</tr>
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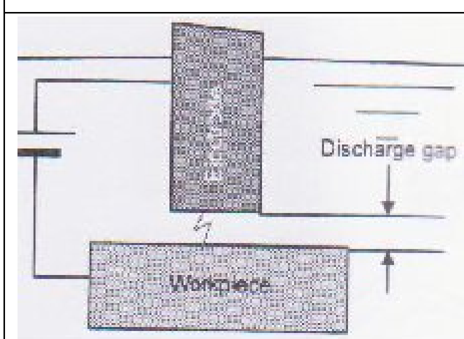
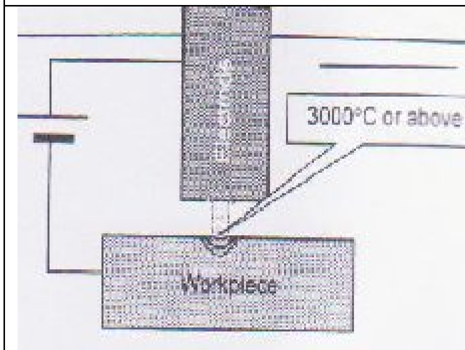
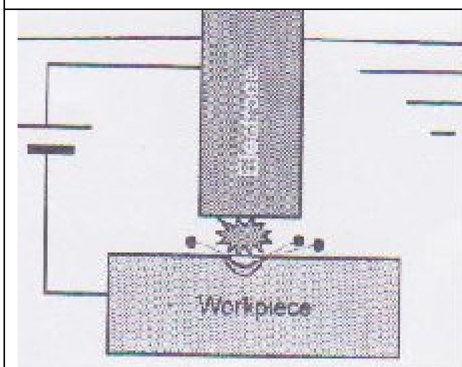
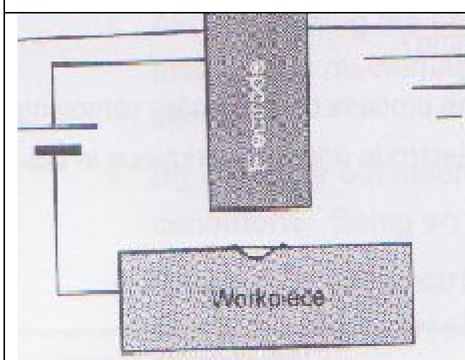
<td>
</td>
<td>When there is some space left between the electrode and the workpiece, the electrode further comes closer to the workpiece by mean of servo motion. When the spaces become several or dozen of microns (discharge gap) insulation between the electrode and the workpiece is broken and spark occurs.</td>
</tr>
</table>

<table>
<tr><td></td><td>• The size of discharge gap depends on the intensity of discharge energy.</td></tr>
<tr><td>
</td><td>An intense energy column of high temperature and voltage is formed at the gap (between the electrode and the workpiece) instantaneously, and is maintained for a certain time. This energy column reaches as high temperature as 3000˚C or above, melting the metallic part of workpiece material with partial ionization.</td></tr>
<tr><td>
</td><td>When an energy column is formed, the dielectric fluid temperature explosively rises, which causes the fluid to expand and evaporate. Part of melted splashes away and a crater is formed on the workpiece.</td></tr>
<tr><td></td><td>Explosion of dielectric fluid disperses the product. When insulation is recovered at the gap, voltage is applied again to start the next electric discharge process.
The above processes are repeated during machining. Once cycle time is approx. several microseconds to several milliseconds, repeating dozens of thousands of times within one second.</td></tr>
</table>

2.3 THE MACHINING CHARACTERISTICS OF EDM

Machining characteristic is best defined as the outcome of the machining process. For example surface roughness (Ra) and microstructure of surface structure and many more.

2.3.1 Surface roughness (Ra)

Roughness is defined as closely spaced, irregular deviation on a small scale. It is expressed in term of its height, width, and the distance along the surface. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The surface roughness depends on the current and electrode that used in machine EDM. Serope Kalpakjian [13].

2.3.2 Microstructure

Oxford dictionary define the microstructure is structure of an organism or object as revealed through microscopic examination and also define the microscopic structure of a material in investigated experiment.

Based on Figure 2.1, effects of flushing rate on difference workpiece material. Wong Y.S, et. al [6] found the effects of flushing rate on the types and distribution of recast layers. There is an optimal dielectric flushing rate of about 13ml/s where the crack density and average thickness of the recast layer are at a minimum for all three materials. The trends for the crack density and recast thickness are similar, being higher at flushing rates below and above a basically similar optimal rate. There is also a minimum of type 3 recast at around the same optimal rate. Type 3 recast layers are associated with increased incidents of cracks. Crack density is higher at the corners and sides. The effects of the quenching property and debris removal ability of the dielectric flow conditions on the recast layers.

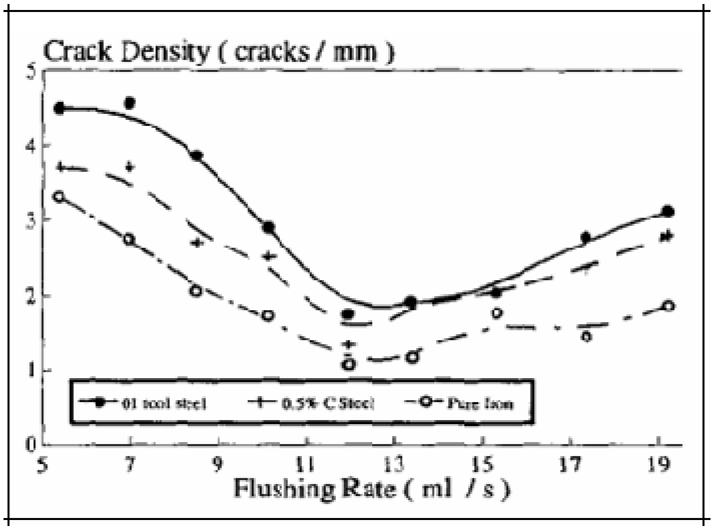


Figure 2.1 Effects of flushing rate on difference workpiece material. [6]

2.4 TYPE OF PARAMETERS IN EDM

Electrode discharge machining parameter can be categorizing into two major groups: electrical and non-electrical parameter. The electrical parameters consist:

i. Electrode material
ii. Average current I (A)
iii. Electrode polarity +/-
iv. working current density, Id (A/cm2)
v. Peak current, Ip(A)
vi. Open gap voltage, Vo (V)
vii. Pulse duration, ti (micro s)
viii. Dielectric
ix. Pause off time, to (micro s)
x. Flushing pressure (Pa)
xi. Average voltage, U (V)
xii. Average current, I (A)
xiii. Jumps speed, (JS)

The non-electrical parameters are servo parameter such as gap and gain. For the EDM machine itself can be spread into four main components which are a machine tool, power supply, computer panel and mechanism. Chen, S.L and Q.C. Hsu. (2003).

Table 2.2: Is show briefly explained about the parameter. [10]

Parameter	**Application**
Electrode material	The tool in the EDM process. It must be made from an electrically conductive material. Its form, or shape, is a mirror image of the finished form or shape desired in the workpiece, with its dimensions adjusted to take into account the amount of over "burn" that occurs.
Electrode polarity (PL)	In EDM, the designation of positive or negative electrical polarity of the electrode. Positive polarity of the electrode (EDM) is considered to be Normal and produces the least amount of electrode wear. The positive or negative polarity depends on the machine.
Peak Current (IP)	The maximum current available from each pulse from the power supply/generator. The peak current is the best defined as the high electrical current that can occur during the discharge. Generally the value of this peak current based on the code, the actual value in unit ampere for this current reading in manual book machine.
Pulse duration (on-time) in time	The duration time of the EDM spark measured in microseconds-μs The longer spark is sustained more is the material removal rate. Except, during roughing all the sparks that leave the tool result in a microscopic removal of particles of the surface. More spark produce much more wear
Pause Duration (off-time) in time	The time between sparks, measured in microseconds. Too short an off-time may result in unstable machining or worse, DC arcing. Longer the off time will cause longer machining time. But this is an integral part of the EDM process must exist. The

	off time also governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo and result slowing down the operating cycle.
Average current	The average value of all the minimum and maximum peaks of amperage in the spark gap, as read on the ammeter
Open gap voltage	The voltage that can be read across the electrode/workpiece gap before the spark begins to flow. See gap voltage.
Dielectric fluid	In EDM, a liquid medium that fills the gap between the electrode and workpiece and acts as an insulator until a specific gap and voltage are achieved. Used to remove chips and cool the electrode/wire and workpiece. It It then ionizes and becomes an electrical conductor, allowing a current (spark) to flow through it to the workpiece. It also serves to cool the work and to flush away the particles generated by the spark.
Flushing pressure	The pressure supplied by pumps in the dielectric system supply fluid to the spark gap duration (sec).
UP: Jump-up machining time	These parameters specifies the duration of the jump-up motion to be used when removing chips from the gap by moving the axes during machining.
DN: Jump-down machining time	This parameters specifies the duration of electric discharge between the jump-down motion and the next jump-up motion in duration (sec)
JS: Jump Speed	The first and second digits of the parameter specify the axis travel speed for jump-up and jump-down motion. This parameter in (m/min).

2.5 ELECTRODE MATERIAL

EDM electrode materials are the components consist of highly conductive and arc erosion-resistant materials. EDM electrodes are manufactured in many forms such as coated wire, tube shaped, or bar stock, depending on the EDM electrode materials used in machine and suitable to cut the workpiece. Below is a brief explanation about the material.

2.5.1 Brass electrode

Brass is easy to machine and can also be die cast or extruded for use in special applications, also brass is not as wear-resistant as other EDM electrode materials. Brass material is used to form EDM wire and small tubular electrode.

2.5.2 Copper tungsten electrode

Is a common base material because it is highly conductive and strong. Copper tungsten electrode is low cost, good machinability, low wear ratio, good finish but not good for high accuracy.

Chen, S.L. et. al [9] found that the electrode copper-tungsten is better than copper as an electrode material due to homogeneous wear ratio in investigation. Che Haron, [11] found that the wear rate of copper tungsten electrode was lower than that of graphite electrode. This is due to the higher melting point of copper tungsten electrode material 1083˚C and graphite 455˚C, which is less eroding than that of the lower melting point graphite electrode material.

2.5.3 Graphite electrode

Che Haron et. al [11] found that the copper electrode is suitable for roughing process, whilst graphite electrode is suitable for finishing process and Combination of both electrodes will improve machining characteristics and surface finish. Graphite electrode is suitable for finishing process.

Graphite (carbon) electrode is the most common type of EDM electrode because it is easily machined, has high wear resistance, and suitable used for various temperature, and is cost effective.

2.6 TUNGSTEN CARBIDE AS A WORKPIECE

This material is combination of tungsten and carbon. Tungsten carbide and other metal carbides are used for EDM workpiece materials because they have high hardness qualities and are wear resistant. Tungsten carbide is an important tool and die material mostly used because of its high hardness, strength and wear resistance. Specific grades are available with corrosion resistance approaching that of noble metals. Conventional grades have sufficient resistance to corrosion-wear conditions for many applications. Tungsten carbide has very high strength for a material so hard and rigid. Compressive strength is higher than virtually all melted and cast or forged metals and alloys. These materials suitable for make insert mould, punch tool and drill bit.

2.7 EFFECTS OF FLUSHING ON CHARACTERISTIC EDM

From the literature review, the effect of dielectric flushing on the machining characteristics was investigated by Lee [5] using peak current of 24 A, gap voltage of 120 V, pulse duration of 12.8 μs, pulse interval of 100 μs, copper tungsten (CuW) as tool electrode materials with negative polarity, and tungsten carbide as the workpiece material used in the experiment. The effects of flushing pressure on the material removal rate, and surface roughness of the workpiece produced are shown in Figure 2.1 and and Figure 2.2.

2.7.1 Effect of flushing pressure on workpiece surface roughness

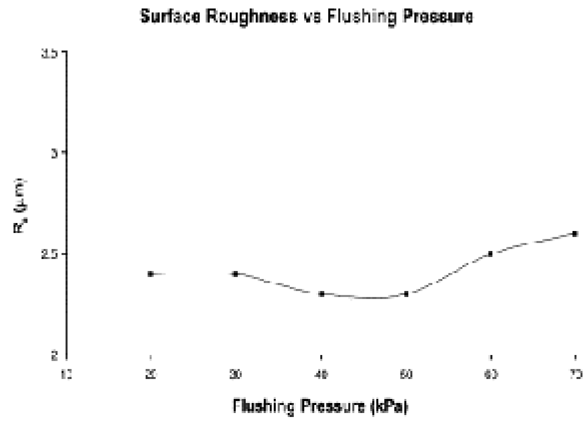


Figure 2.2 Effect of flushing pressure on workpiece surface roughness. [5]

By referring the Figure 2.2, Lee [5] investigated flushing pressure at 40kPa to 50kPa and the surface roughness is smoothing proportionate. When increase flushing pressure the rate of value surface roughness also increase. Factor of flushing pressure is important to remove gaseous and solid debris generated during EDM in the spark gap between material tool and workpiece. Uneven of electrode wear can be affected the accuracy and surface roughness that normally come from improper flushing.

Lonardo [4] made an experimental analysis on Chromium (Cr), Molybdenum (Mo), and Vanadium (V) steel die casting by using both copper and graphite electrode. In experimental investigation, flushing produces has significant increase in root mean square (rms) slope (α = 0.99). Interaction between flushing and electrode size appears also significant at same level. Height surface roughness consider strong dependence on the electrode material (α = 0.99). Copper electrode produces lower height. The remaining factors have no significant influence on these parameters.